Int J Clin Exp Med 2022;15(11):357-367
www.ijcem.com /ISSN:1940-5901/IJCEM0143674

Review Article

Research advances in deep learning based double lumen endotracheal tubes

Fei-Yang Pu[1*], Wei Wang[2*], Hai-Po Cui[1], Zhan Zhao[1], Jing-Cheng Lang[1], Wen-Hui Yan[1], Zui Zou[3], Hong Liu[4]

[1]Shanghai Institute for Minimally Invasive Therapy, University of Shanghai for Science and Technology, Shanghai 200093, China; [2]Navy Medical Center PLA, Shanghai 200433, China; [3]School of Anesthesiology, Naval Medical University, Shanghai 200433, China; [4]Information Center, The Second Affiliated Hospital of Naval Medical University, No. 415, Fengyang Road, Huangpu District, Shanghai, China. [*]Equal contributors.

Received April 21, 2022; Accepted October 22, 2022; Epub November 15, 2022; Published November 30, 2022

Abstract: The double-lumen tube is the most commonly used tool for one-lung ventilation in clinical practice. The combination of visualization technology and the double-lumen tube makes intubation more rapid and precise, avoiding complications. With the success of Deep Learning in the field of endoscopy, Deep Learning assisted double-lumen tube insertion has become possible. However, in the past five years, few studies have focused on this aspect. In this paper, we review the development of double-lumen tube, including improvements in structural design, selection of optimal dimensions, and advances in visualization techniques for intubation. The possibility of applying Deep Learning to double-lumen tube, such as predicting the optimal size of double-lumen tube by regression models, is discussed. Particularly, the role of Object Detection algorithm in assisting intubation insertion is highlighted. Challenges of current techniques and future solutions are also discussed.

Keywords: Double lumen tube, vivasight, fiberoptic bronchoscopy, videolaryngoscope, deep learning

Introduction

The evolution from a single lumen tube (SLT) to double lumen tubes (DLT) in the 1880s contributed to the rapid development of respiratory physiology and independent spirometry [1]. In the following decades, different techniques of securing the airways and selective one-lung ventilation largely contributed to the development of intra-thoracic surgery and made complex lung, esophageal, mediastinal and chest wall procedures possible [1-3]. Among them, DLT is the gold standard for performing various surgical procedures such as lung separation/isolation and is favored by most anesthesiologists [2].

A large number of medical images generated during medical examinations, and increased computing power has facilitated the development and application of Artificial Intelligence (AI) tools in automated image analysis [4, 5]. Convolutional Neural Networks (CNN), a class of feedforward neural networks that include convolutional computation with a deep structure, are one of the representative algorithms of Deep Learning (DL), and their main applications are in image classification and recognition.

In recent years, CNN have driven the continuous development in the field of medical imaging. In endoscopy, computer aided diagnosis can be used to reduce workload and errors while improving efficiency of physicians. For example, Guo et al. [6] developed a computer aided diagnostic system for endoscopic detection of four types of lesions: polyps, advanced cancer, erosions/ulcers, and varicose veins, and Saraiva et al. [5] created an algorithm for automatic detection of blood and blood residue in the intestinal lumen during endoscopy. There are also many applications of DL for radiological images, including classification, segmentation, detection, etc. [7] For example, CNN-based analysis of brain Magnetic Resonance Imaging (MRI) images [8] and DL segmentation networks for Computed Tomography (CT) or MRI images automatically segment target organs or lesion parts [9], and the segmentation results can be used for subsequent 3D reconstruction and surgical planning, which greatly reduces the time spent on manual segmentation.

The purpose of this review is to summarize current progress of DLT and make recommendations for post-need optimization by examining the use of DLT in OLV. It includes a description of DLT design, DLT indications, the use of visualization on DLT, and studies combining DLT with DL.

Literature search

A literature search was performed in PubMed, Web of Science, and Science Direct, using the terms "Videolaryngoscope AND Double Lumen Tube", "Fiberoptic bronchoscopy AND Double Lumen Tube", "VivaSight AND Double Lumen Tube", and the search period was from 2017 to 2022. A total of 149 studies were included. After reading the abstracts, we removed identical literature and the studies containing Single Lumen Tubes. A total of 28 studies were finally included [2, 10-36]. As shown in **Table 1**, the focus and principal conclusions of all included literature are summarized.

However, a literature search using the terms "Machine Learning", "Artificial Intelligence", and "Deep Learning" with the terms "Double Lumen Tube", "Videolaryngoscope", "Fiberoptic bronchoscopy", and "VivaSight", by using the logical conjunction "AND", revealed no relevant studies. Therefore, this review analyzes the possibility of combining DL with DLT by examining studies related to DL in the field of endoscopy and medical imaging.

Lung isolation techniques

Lung isolation techniques have three main purposes [2, 3]: 1. To prevent contamination of healthy lungs by pus, blood, or other fluids from the contralateral lung. 2. To facilitate exposure of intrathoracic anatomy in diagnostic and therapeutic procedures. 3. To provide differential ventilation and airway protection in unilateral chest disease.

Indications for lung isolation techniques include mainly absolute and relative indications, and **Table 2** summarizes the common indications and targets for the use of two techniques of lung isolation [2, 3].

Double lumen tube

Design of DLT

Most modern DLTs are now based on Robertshaw designs [25, 27]. All DLTs contain tubes connected together, the shorter one terminating in the trachea and the longer one extending further into the left/right main bronchus [25]. The cuff on the DLT are color coded, with the main tracheal cuff commonly being clear and the left and right bronchial cuff commonly being blue [3]. The proximal portion of the DLT is graduated to measure the depth of insertion. Some DLTs have a radiopaque marker drawn on them to facilitate localization using fiberoptic bronchoscopy (FOB) or radiography [3].

The material of the DLT has evolved from the previously used rubber to silicone resin and polyvinyl chloride tube [3, 27] that allows for diameter ratio of inner to outer tube than before, which facilitates insertion into the right or left main bronchus through the upper airway. The new materials also allow for a transparent wall to detect exhaled water vapor, blood and secretions [3].

Selection of left or right DLT

Different shapes of DLTs were designed for the left and right bronchial tubes due to the anatomical differences, respectively [3, 25, 27]. The right main bronchus is straighter and shorter than the left main bronchus, so the bronchial cuff of the left DLT is cylindrical, while the bronchial cuff of the right DLT is inclined and circular to facilitate ventilation of the right upper lobe [3], as shown in **Figure 1**.

In general, the left DLT is used for right-sided intrathoracic surgery, while the right DLT is used for left-sided surgery. The length of the endobronchial segment that can be adjusted without interfering with the bronchial bifurcation is called the "margin of safety" [3, 27]. The left DLT is more commonly used because it has a broader safety margin compared to the right DLT [3, 25, 27]. In addition, left DLT is easier to locate and safer to manage intraoperatively [14]. In contrast, right DLT must be used for patients whose tumors obstruct the left main bronchus. Right DLT is recommended for patients with distorted anatomy, external com-

Table 1. Summary of literature studies on DLT in airway management

Study	Focus of Study	Principal Conclusions
Huybrechts et al. [2]	Methods commonly used for OLV*.	DLT* is widely used for single lung ventilation.
Ajimi et al. [10]	To evaluate the utility of two video laryngoscopes, the Airtraq DL and the AWS-200, during intubation.	In non-difficult airway patients, intubation time with the Airtraq DL was less than that of the AWS-200.
Bakshi et al. [11]	Comparison of intubation times using the McGrath MAC VL and Macintosh laryngoscope (DL).	The McGrath MAC VL and the Macintosh laryngoscope have similar intubation times. However, the VL has better visualization of the vocal cords, reduced need for external laryngeal manipulation and fewer complications.
Belze et al. [12]	Comparison of Glidescope and Airtraq insertion in patients with difficult airways.	There was no difference in the success rate of tracheal intubation in patients with difficult airways when using the Glidescope or Airtraq devices.
Benison et al. [13]	A case of unexpected difficult intubation despite preoperative evaluation is reported.	The case highlights importance of ventilation over intubation, importance of preoperative evaluation, possibility of failure of videolaryngoscopy, importance of avoidance of fixation error and fundamental role of fiberoptic, with spontaneous breathing, for difficult airway management.
Cheng et al. [14]	To investigate the incidence of tracheal bronchus (TB) and explore its implication for lung isolation.	Preoperative diagnosis of TB is important when lung isolation is needed. The left-sided DLT can be used for most patients with a TB.
Cierniak et al. [15]	To evaluate the effectiveness of Cmac and VivaSight in the hands of users who are not trained in intubation.	According to subjective opinion, the Cmac is easier to operate than the VivaSight. Even during the learning period, the videolaryngoscope can be an important tool for training on new intubation methods.
D'Anto et al. [16]	Describes a hospital-based The Health Technology Assessment process (cost-impact assessment). The program was used to compare an innovative device with an integrated camera for bronchial intubation in thoracic surgery.	The introduction of innovative devices can significantly reduce intubation time, overall procedure time and cost of the study. These results also confirm the usefulness of the hospital-based The Health Technology Assessment program.
Dharmalingam et al. [17]	The Full view VDLT can minimize or circumvent the use of FOB during OLV, and reduce the time taken to isolate the lungs thus reducing aerosol in the theater.	The Full view VDLT is an efficient and safe alternative for lung isolation at this time of the COVID-19 pandemic.
Ellensohn et al. [18]	The DLT dimensions were measured by CT for comparison with the three manufacturer's recommended dimensions.	A significant number of the three manufacturer-recommended DLT sizes are incompatible with the airway dimensions of individual patients.
El-Tahan et al. [19]	Compare the time required for successful DLT intubation by users with mixed experience using a Macintosh or GlideScope with that using an Airtraq or King Vision.	When used by operators with mixed experience, the Airtraq requires less time for DLT cannulation and is easier to use than the GlideScope.
Gil et al. [20]	Reviewing whether VivaSight-DL can replace Fiberoptic bronchoscopy.	The VivaSight-DL with embedded camera allows for airway management and continuous observation on a portable external monitor, as well as single-lung isolation during anesthesia.
Grensemann et al. [21]	Compare the success rates of direct laryngoscopy and video guidance.	In this pilot study, VivaSight did not show an advantage.
Heir et al. [22]	To compare the incidence of fiberoptic bronchoscope (FOB) use during verification of initial placement and for reconfirmation of correct placement following repositioning, when either a double-lumen tube (DLT) or video double-lumen tube (VDLT) was used for lung isolation during thoracic surgery.	This study demonstrated a reduction of 86.8% in FOB use, which was a similar reduction found in other published studies.
Heseltine et al. [23]	Guided DLT insertion using Fiberoptic bronchoscopy.	DLT should be placed using a Fiberoptic bronchoscope. This allows correct positioning of the bronchial lumen in the chosen mainstem bronchus.

Huang et al. [24]	To compare the performances of the GlideScope, the C-MAC videolaryngoscope and the Macintosh laryngoscope in DLT intubation.	Compared with the Macintosh laryngoscope, the GlideScope (R) and C-MAC (R) (D) videolaryngoscopes may not be recommended as the first choice for routine DLT intubation in patients with predicted normal airways.
Iyer et al. [25]	Contemporary lung isolation devices and the important factors that influence device selection during lung transplantation are discussed.	The left DLT remains the most popular device for OLV.
Larsen et al. [26]	Comparing the Cost of VivaSight and Traditional DLT.	VivaSight-DL is more cost-effective.
Lee et al. [27]	This article outlines the development and use of the currently available DLTs and bronchus-blockers.	
Liu et al. [28]	To assess the feasibility and accuracy of using chest computed tomography (CT) to measure the distance between the vocal cords and the neck as a guide for left-sided double-lumen tube (LDLT) cannulation.	The measurement of the distance between the vocal cords and the neck based on chest CT is used as a guide for LDLT intubation and is more effective and accurate than the blind method.
Mathew et al. [29]	Compare the average time to perform intubation on CMAC and Macintosh.	Macintosh blade is as good as CMAC blade to facilitate DLT intubation in adult patients with no anticipated airway difficulty, however CMAC was superior as it offers better laryngoscopic view, needed less force, and fewer external laryngeal manipulations.
Mittal et al. [30]	C-MAC video nosepiece.	Successful use of the C-MAC video nasoscope as a tool for awake intubation and dual-lumen tube placement.
Onifade et al. [31]	The utilization rate of fiberoptic bronchoscopy for intubation with VivaSight-DLT or conventional DLT was compared.	The VivaSight-DLT has significantly lower fiberoptic bronchus usage, significantly faster placement, and significantly fewer intraoperative misalignments compared to conventional DLT, but does not result in a significant cost reduction.
Rapchuk et al. [32]	Evaluating the use of VivaSight-DLT.	The VivaSight-DL represents a novel method of OLV allowing rapid identification of intraoperative airway problems and reducing the need for fibreoptic bronchoscopy.
Ryu et al. [33]	Compare the intubation results of fiberoptic bronchoscopy and Macintosh laryngoscopy.	The fiberoptic bronchoscopy-guided DLT placement method is more effective compared to the conventional method.
Seo et al. [34]	Introducing a new DLT, ANKOR DLT, for difficult airways.	ANKOR DLT would be a feasible choice to achieve successful blind lung isolation when the use of FOB is impossible to achieve the optimal lung isolation.
Tan et al. [35]	Report of a case of intubation in a young man diagnosed with advanced cardia incontinentia with a giant esophagus.	Prone position to maintain proper DLT placement and fiberoptic bronchoscopy to address DLT dislodgement.
Yu et al. [36]	To explore an effective method to address the difficulty of repositioning due to right upper lobe occlusion during surgery.	Repositioning of R-DLT from the right main bronchus to the left main bronchus has good clinical performance without causing additional damage.

*DLT: Double Lumen Tubes; OLV: One-Lung Ventilation.

Table 2. Indications for lung isolation techniques

		Indications	Main goal
Absolute indications		Unilateral lung abscess or cyst	Contralateral lung protection
		Unilateral pulmonary hemorrhage (thromboembolism, aneurysm)	Contralateral lung protection
		Bronchoalveolar lavage with saline to treat alveolar proteinosis	Contralateral lung protection
		Bronchopulmonary fistula, trachea-bronchial injury	Secure the airways and gas exchange
		Severe unilateral disease (giant emphysematous bullae)	Differential lung ventilation
		Lung transplantation	Secure the airways and differential ventilation
Relative indications	High priority	Pneumonectomy, sleeve resection on the bronchial mainstem	Surgical exposure
		Tumor obstructing the main bronchial stem	
		Thoracic aneurysm with cardiopulmonary bypass	Surgical exposure
		Lobectomy and lesser lung resection (any surgical approacha)	Surgical exposure
	Low priority	Interventions on the pleura and mediastinal structures	Surgical exposure
		Oesophagectomy	Surgical exposure
		Orthopedic surgery on the chest, thoracic spine surgery	Surgical exposure
		Minimally invasive cardiac surgery	Surgical exposure

Figure 1. DLT. left, left DLT; right, right DLT.

pression of the left main bronchus by aortic aneurysms or lymph nodes [36].

Size selection of DLT

Current DLT manufacturers offer various sizes of DLTs, generally including 26Fr, 28Fr, 32Fr, 35Fr, 37Fr, 39Fr, 41Fr [25, 27]. **Table 3** summarizes the parameters of different sizes of DLTs [3].

The conditions for a suitable DLT include [2, 31, 37]: 1. The DLT is inserted smoothly and reaches the intended bronchus correctly or after adjustment. 2. The main tracheal cuff is injected with 2-6 ml of gas and the intracapsular pressure is less than 25 cmH_2O, and there is no air leak at the peak of 30 cmH_2O of positive pressure ventilation airway. 3. The bronchial cuff is injected with 1-3 ml of gas and the intracapsular pressure is less than 20 cmH_2O, and there is good isolation of both lungs at the peak of 30 cmH_2O of positive pressure ventilation airway. The two lungs are well isolated at the peak of 30 cmH_2O of the ventilation airway. When the resistance to tube insertion is obvious, the main tracheal cuff is filled with less than 2 ml of air, and the bronchial cuff is filled with less than 1 ml of air or even no air, then the smaller size is better. When the main tracheal cuff is filled with more than 6 ml of air and the bronchial cuff is filled with more than 3 ml of air, the size of the DLT selected should be small.

One of the main challenges that DLT currently faces is the lack of objective methods and guidelines for selecting the appropriate size and optimal depth [25]. Generally speaking, the DLTs in sizes 35Fr or 37Fr are available for most adult females, while DLT in sizes 39Fr or 41Fr are suitable for the average adult male [2, 3, 23, 25, 27]. However, Ellensohn's team [18] found a considerable proportion of the recommended DLT sizes from all three manufacturers were incompatible with individual patient's lower airway dimensions. Undersized or oversized DLTs can lead to serious airway complications such as sore throat, tracheal or bronchial hematoma, and tracheal or bronchial rupture [2, 25]. The most accurate way to select the size of the left DLT is to measure the width of the bronchus and the outer diameter of the DLT, and then select the largest tube that safely fits that bronchus. Measurement of the size

Table 3. Outside diameter, inside diameter and length of different sizes of DLT

Size	OD* (mm)	Bronchus ID* (mm)	Trachea ID* (mm)	Length (mm)
26	8.7-9.3	3.0	3.0	280
28	9.3-10.2	3.2	3.1	280
32	10.5-11.2	3.4	3.5	300
35	12.0-13.5	4.3	4.5	300-310
37	13.3-14.0	4.5	4.7	310-320
39	13.8-14.3	4.9	4.9	330-340
41	13.7-14.9	5.4	5.4	340-350

*OD: Outer Diameter; ID: Inner Diameter.

of the trachea and bronchi is usually based on an image such as a CT or X-ray of the chest taken before anesthesia [38].

Visualization technology and DLT

Current visualization techniques applied to DLT include videolaryngoscopy guided DLT, FOB guided DLT, and VivaSight. Its primary function is to assist intubation operators to place DLT in a rapid and effective way, especially for patients with difficult airways [13]. For example, Mittal et al. [30] used videolaryngoscopy as a tool for awake intubation of difficult airways and DLT placement.

Videolaryngoscope

The role of videolaryngoscope in airway management is becoming increasingly important [10]. Videolaryngoscope provides operators with a view of the vocal cords, which can improve the success rate of intubation while reducing intubation time. However, the time required to assist intubation with videolaryngoscope still varies depending on the experience of operators. **Figure 2** shows the videolaryngoscope.

Figure 2. Videolaryngoscope.

Videolaryngoscopes commonly used in clinical practice include C-MAC, King Vision, Glidescope, McGrath MAC, and different types of videolaryngoscopes have their advantages and disadvantages in assisting DLT. El-Tahan et al. [19] compared three different laryngoscopes and concluded that Airtraq and King Vision provide a wider field of view, a smaller blade, and a channel for guiding DLT compared to the Glidescope, while also having a larger outer diameter and a more rigid design. Mathew et al. [29] concluded that C-MAC blade is superior to Macintosh blade by comparing two videolaryngoscopes for DLT in patients undergoing elective open-heart surgery, providing not only a better field of view but also requiring less effort and less external manipulation. Huang et al. [24] experimentally illustrated the higher success rate of Macintosh compared to Glidescope and C-MAC on the first attempt. Bakshi et al. [11] compared the two videolaryngoscopy assisting endobronchial intubation with DLT, McGrath MAC and Macintosh, and concluded that although the time taken in the two modalities was similar, McGrath MAC had better visualization of vocal folds as well as fewer external manipulations. In addition, Belze et al. [12] found similarity in intubation success between the two videolaryngoscopes when faced with patients with difficult airways using the Glidescope and AirTraq. In summary, different types of videolaryngoscopes for difficult airways can improve the success rate of first intubation; however, different types of videolaryngoscopes have different blade angles and field of view,

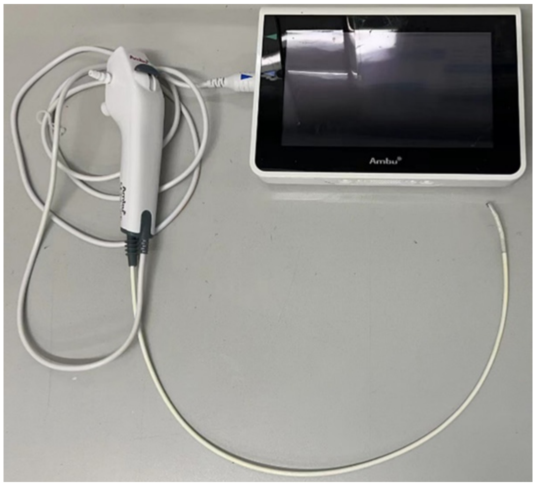

Figure 3. Fiberoptic bronchoscope.

which can have an impact on the intubation time of operators and the availability of external manipulation.

Fiberoptic bronchoscopy

The use of FOB to guide DLT intubation also involves the use of videolaryngoscope, which is used to assist in the insertion of the DLT into the trachea, and the FOB (**Figure 3**), which is used to assist in pushing DLT into the right or left bronchi. In the case of video laryngoscopy only, DLT can only be inserted blindly after entering the subglottic. However, two studies [39, 40] have shown that the use of FOB assisting endobronchial intubation with DLT is more accurate than blind insertion, but more complex operations make the insertion time relatively longer.

Confirming the accurate position of DLT is essential to ensure that DLT is working properly, however, clinical assessment by examination and extrapolation alone to confirm the correct position of DLT is unreliable, so visual confirmation under FOB guidance is currently used as the gold standard in clinical practice [31-34]. However, the use of FOB is inexperienced and expensive for many anesthesiologists, so Liu et al. [28] used CT images of the chest as a guide to left DLT by measuring the distance between the vocal cords and the ramus, which is a non-visual method but equally effective and accurate.

VivaSight

Although FOB addresses the visualization of tracheal and bronchial anatomy, Campos et al. [41] observed a high incidence of DLT malposition even among experienced anesthesiologists. Although FOB also addresses DLT malposition [35], the FOB commonly used in clinical practice does not allow continuous intraoperative monitoring of the airway and therefore cannot respond to possible adverse events in the airway in a timely and effective manner.

With the miniaturization of cameras and light sources, this problem has a new solution. VivaSight builds on the traditional DLT by embedding a camera and light source so that continuous airway visualization can be achieved during intubation [20, 25, 32]. Heir et al. [22] showed that the use of VivaSight was effective in reducing the use of FOB in positioning and lung isolation procedures [32], and that the use of VivaSight was cost-effective compared to FOB assisted intubation [16, 26]. Meanwhile, Grensemann et al. [21] showed no difference in first intubation success rates between VivaSight and FOB-assisted intubation in patients with non-difficult airways, but the presence of secretions in a difficult airway may cause camera contamination of the VivaSight. The VivaSight is now equipped with a flushing port that allows the camera to be cleaned at any time during intubation using saline, thus avoiding camera contamination [17, 32]. In addition, several studies [16, 17] have found that the use of VivaSight is faster compared to FOB-assisted intubation, reducing procedure time by 36% and allowing for faster mastery for novices [15].

Feasibility analysis of DLT combined with deep learning

Predicting DLT size based on artificial intelligence

There are two main methods to select the appropriate DLT size: one is to calculate the DLT size by a formula, and the other is to measure the actual size of the trachea and bronchi in preoperative images to determine the DLT size. For example, Sydiuk et al. [42] retrospectively studied 192 patients with left DLT using five features such as gender, height, weight, diameter of the left main bronchus and age as variables and constructed a generalized regression model to develop a standard mathematical formula to determine the size of left DLT. Liu et al. [38] determined the left DLT by preoperative CT measurements of the cricoid cartilage and the diameter of the left main bronchus.

However, these two traditional methods for selecting the appropriate DLT size have obvious drawbacks. On the one hand, the formulae obtained from the generalized regression model are based on the patient data obtained in the study, and the insufficient amount of data makes the obtained formulae not universal. On the other hand, manual measurements to calculate the DLT size are more accurate but time-consuming, and some patients lack imaging data.

DL can effectively solve the above problems. There are many methods to predict results through Artificial Intelligence (AI), including Machine Learning (ML), such as Linear Regression (LR), Random Forest (RF), Support Vector Machine (SVM), and DL. These methods can effectively obtain the relationship between independent variables (features) and dependent variables (outcomes), while data can be continuously collected to improve the accuracy and general adaptation of the model. Meanwhile, Convolutional Neural Network (CNN) can effectively extract feature information from images and predict DLT size by the extracted features, which can significantly improve efficiency compared to manual measurement by doctors.

Deep learning assisted visualization DLT

Existing visualization intubations view the interior of the airway through a handheld monitor, however, after rotating the camera, anesthesiologists may not be able to distinguish between the left/right main bronchus clearly. Yoo's team [43] compared 10 DL models to classify left/right bronchi and carina to address the problem of confusing depth and direction during DLT insertion, and obtained very good results. However, the model is unable to identify possible secretions of the airway, such as blood and sputum.

The above problems can be effectively solved by using the Object Detection algorithm. The task of Object Detection is to determine the classification and location of the object. Therefore, for the left and right bronchi of the airway, sputum, blood clots and polyps, the algorithm can determine their location in the airway and their classification. Livovsky et al. [44] performed well in detecting polyps in colonoscopy using Object detection. Therefore, Object Detection combined with visualization devices is feasible. Object Detection allows continuous airway detection, something that classification models cannot do.

Conclusion

In many DLT studies, the choice of DLT size and left/right is critical. Currently, the selection of DLT size is generally derived by formula calculation or manual measurement of radiographic images. However, formula calculation has a narrow range of applicability and manual measurement is slow. It is worth noting that DL models can effectively solve the above problems. As for the choice of DLT, generally the left DLT is chosen for right-sided intrathoracic surgery and the right DLT is chosen for left-sided surgery; however, the left DLT is preferred in non-special cases because of its simpler positioning and safer intraoperative management.

Visualization techniques make DLT intubation easier, especially for difficult airways. Videolaryngoscopy reduces injury and postoperative complications compared to blind insertion of the DLT into the airway. FOB is the gold standard for DLT localization and effectively reduces the risk of intraoperative DLT malposition compared to the traditional auscultation method. VivaSight enables continuous visualization and allows real-time intraoperative monitoring of the airway to prevent adverse events.

With ever advancing airway identification technology based on AI, DL-based visualization DLT may be also a focus of the future research. Currently, DLT can only visualize the airway, but the combination of Object Detection and visualization techniques can continuously detect the airway. In the future, AI is not only expected to assist anesthesiologists in intubation, but will also guide robots to perform automatic intubation and fully automate DLT intubation.

Acknowledgements

This work was supported by Shanghai Municipal Science and Technology Major Project (No. 2021SHZDZX), Natural Science Foundation of

Shanghai (No. 19ZR1435300 and 20ZR14-37700), the scientific research project of Changzheng Hospital (No. 2019CZJS213), and the talent project of Science and Technology Commission of Shanghai Municipality (No. 20XD1434400), P. R. China.

Disclosure of conflict of interest

None.

Address correspondence to: Hai-Po Cui, Shanghai Institute for Minimally Invasive Therapy, University of Shanghai for Science and Technology, Shanghai 200093, China. Tel: +86-21-55271290; E-mail: h_b_cui@163.com; Hong Liu, Information Center, the Second Affiliated Hospital of Naval Medical University, No. 415, Fengyang Road, Huangpu District, Shanghai, China. Tel: +86-13917038549; E-mail: liuhong@smmu.edu.cn

References

[1] Shoni M and Rodriguez G. Intraoperative anesthetic management of the thoracic patient. Thorac Surg Clin 2020; 30: 279-291.
[2] Huybrechts I, Tuna T and Szegedi LL. Lung separation in adult thoracic anesthesia. Saudi J Anaesth 2021; 15: 272-279.
[3] Licker M, Le Guen M, Diaper J, Triponez F and Karenovics W. Isolation of the lung: double-lumen tubes and endobronchial blockers. Trends in Anaesthesia and Critical Care 2014; 4: 47-54.
[4] Castiglioni I, Rundo L, Codari M, Di Leo G, Salvatore C, Interlenghi M, Gallivanone F, Cozzi A, D'Amico NC and Sardanelli F. AI applications to medical images: from machine learning to deep learning. Phys Med 2021; 83: 9-24.
[5] Mascarenhas Saraiva M, Ribeiro T, Afonso J, Ferreira JPS, Cardoso H, Andrade P, Parente MPL, Jorge RN and Macedo G. Artificial intelligence and capsule endoscopy: automatic detection of small bowel blood content using a convolutional neural network. GE Port J Gastroenterol 2021; 29: 331-338.
[6] Guo LJ, Gong H, Wang QS, Zhang QY, Tong H, Li J, Lei X, Xiao X, Li CH, Jiang JS, Hu B, Song J, Tang CW and Huang ZY. Detection of multiple lesions of gastrointestinal tract for endoscopy using artificial intelligence model: a pilot study. Surg Endosc 2021; 35: 6532-6538.
[7] Yamashita R, Nishio M, Do RKG and Togashi K. Convolutional neural networks: an overview and application in radiology. Insights Imaging 2018; 9: 611-629.
[8] Bernal J, Kushibar K, Asfaw DS, Valverde S, Oliver A, Marti R and Lladó X. Deep convolutional neural networks for brain image analysis on magnetic resonance imaging: a review. Artif Intell Med 2019; 95: 64-81.
[9] Hesamian MH, Jia W, He XJ and Kennedy P. Deep learning techniques for medical image segmentation: achievements and challenges. J Digit Imaging 2019; 32: 582-596.
[10] Ajimi J, Nishiyama J, Masuda R, Shibata T and Suzuki T. Airtraq DL and AWS-200 for double-lumen endotracheal tube intubation: a prospective randomized clinical trial. Tokai J Exp Clin Med 2018; 43: 161-167.
[11] Bakshi SG, Gawri A and Divatia JV. McGrath MAC video laryngoscope versus direct laryngoscopy for the placement of double-lumen tubes: a randomised control trial. Indian J Anaesth 2019; 63: 456-461.
[12] Belze O, Lepage E, Bazin Y, Kerourin P, Fusciardi J, Remérand F and Espitalier F. Glidescope versus Airtraq DL for double-lumen tracheal tube insertion in patients with a predicted or known difficult airway A randomised study. Eur J Anaesthesiol 2017; 34: 456-463.
[13] Benison E. Use of the VivaSight-DL (AMBU®) double lumen tube for oesophageal surgery. Trends in Anaesthesia and Critical Care 2018; 23: 36-37.
[14] Cheng LL, Liu SQ, Qi WX and Dong YJ. The incidence of tracheal bronchus in thoracic surgery patients and its implication for lung isolation: a retrospective cohort study. J Cardiothorac Vasc Anesth 2020; 34: 3068-3072.
[15] Cierniak M, Pikala M, Jaskółkowska J, Nowakowski M, Balcerzak B and Gaszynski T. Comparison of Cmac vs Vivasight devices in terms of time and effectiveness of intubation among medical students. Pol Merkur Lekarski 2017; 43: 207-212.
[16] D'Antò M, Cosentino C, Cuomo A, Accardo R, Bifulco P, Donisi L and Romano M. Evaluation of a new endobronchial double lumen tube with integrated camera: a hospital based HTA experience. 15th Mediterranean Conference on Medical and Biological Engineering and Computing (MEDICON) 2019; 76: 1028-1037.
[17] Dharmalingam SK, George G, Davis K, Kuppuswamy B, Gnanamuthu BR and Sahajanandan R. Safety and efficacy of video DLT (VDLT) for lung isolation during the COVID-19 pandemic. Ann Card Anaesth 2022; 25: 107-111.
[18] Ellensohn J, Hillermann T, Steinauer A, Hegland N, Schnitzler S, Welter J, Weiss M and Dullenkopf A. Compatibility of left-sided double-lumen endobronchial tubes with tracheal and bronchial dimensions: a retrospective comparative study. Minerva Anestesiol 2022; 88: 121-128.
[19] El-Tahan MR, Khidr AM, Gaarour IS, Alshadwi SA, Alghamdi TM and Al'ghamdi A. A comparison of 3 videolaryngoscopes for double-lumen

tube intubation in humans by users with mixed experience: a randomized controlled study. J Cardiothorac Vasc Anesth 2018; 32: 277-286.
[20] Gil MG, Carrasco I, Kot P, Murcia M, Morales J, Broseta A, Guijarro R and de Andrés JA. Retrospective evaluation of the use of left sided double-lumen endobronchial tubes with an embedded camera VivaSight-DL® during lung separation in 30 thoracic surgery patients. J Cardiothorac Vasc Anesth 2019; 33: S119.
[21] Grensemann J, Eichler L, Wang NW, Jarczak D, Simone M and Kluge S. Endotracheal tube-mounted camera-assisted intubation versus conventional intubation in intensive care: a prospective, randomised trial (VivaITN). Crit Care 2018; 22: 235.
[22] Heir JS, Guo SL, Purugganan R, Jackson TA, Sekhon AK, Mirza K, Lasala J, Feng L and Cata JP. A randomized controlled study of the use of video double-lumen endobronchial tubes versus double-lumen endobronchial tubes in thoracic. J Cardiothorac Vasc Anesth 2018; 32: 267-274.
[23] Heseltine N and Knowles A. Bronchoscopic insertion of double lumen endotracheal tubes and bronchial blockers. Anaesthesia & Intensive Care Medicine 2021; 22: 142-147.
[24] Huang P, Zhou RL, Lu ZX, Hang YN, Wang SJ and Huang ZL. GlideScope (R) versus C-MAC (R)(D) videolaryngoscope versus Macintosh laryngoscope for double lumen endotracheal intubation in patients with predicted normal airways: a randomized, controlled, prospective trial. BMC Anesthesiol 2020; 20: 119.
[25] Iyer MH, Kumar N, Hussain N, Essandoh M, Kumar J, Gorelik L, Flores AS, Bhandary SP and Bhatt A. Airway management during anesthesia for lung transplantation: double-lumen tube or endobronchial blocker? J Cardiothorac Vasc Anesth 2021; 35: 1286-1291.
[26] Larsen S, Holm JH, Sauer TN and Andersen C. A cost-effectiveness analysis comparing the vivaSight double-lumen tube and a conventional double-lumen tube in adult patients undergoing thoracic surgery involving one-lung ventilation. Pharmacoecon Open 2020; 4: 159-169.
[27] Lee KG. Airway apparatus for thoracic surgery. Anaesthesia and Intensive Care Medicine 2017; 18: 620-625.
[28] Liu Z, Zhao L, Jia QQ, Yang XC, Liang SJ and He WS. Chest computed tomography image for accurately predicting the optimal insertion depth of left-sided double-lumen tube. J Cardiothorac Vasc Anesth 2018; 32: 855-859.
[29] Mathew A, Chandy J, Punnoose J, Gnanamuthu BR, Jeyseelan L and Sahajanandan R. A randomized control led study comparing CMAC video laryngoscope and Macintosh laryngoscope for insertion of double lumen tube in patients undergoing elective thoracotomy. J Anaesthesiol Clin Pharmacol 2021; 37: 266-271.
[30] Mittal AK, Goel N and Dubey J. C-MAC D-Blade video laryngoscope for awake double lumen tube placement: a case report. Trends in Anaesthesia and Critical Care 2018; 18: 34-36.
[31] Onifade A, Lemon-Riggs D, Smith A, Pak T, Pruszynski J, Reznik S and Moon TS. Comparing the rate of fiberoptic bronchoscopy use with a video double lumen tube versus a conventional double lumen tube-a randomized controlled trial. J Thorac Dis 2020; 12: 6533-6541.
[32] Rapchuk IL, Kunju S, Smith IJ and Faulke DJ. A six-month evaluation of the VivaSight(TM) video double-lumen endotracheal tube after introduction into thoracic anaesthetic practice at a single institution. AnaesthIntensive Care 2017; 45: 189-195.
[33] Ryu T, Kim E, Kim JH, Woo SJ, Roh WS and Byun SH. Comparing the placement of a left-sided double-lumen tube via fiberoptic bronchoscopy guidance versus conventional intubation using a Macintosh laryngoscope, to reduce the incidence of malpositioning: study protocol for a randomized controlled pilot trial. Trials 2019; 20: 51.
[34] Seo Y, Kim N, Paik HC, Park D and Oh YJ. Successful blind lung isolation with the use of a novel double-lumen endobronchial tube in a patient undergoing lung transplantation with massive pulmonary secretion A case report. Medicine 2019; 98: e16869.
[35] Tan KM, Yeap BT and Dewi SS. Pitfalls of double lumen endotracheal tube in prone position during a thoracoscopic and laparoscopic assisted esophagectomy (TLAE): a sabah experience. Gazi Medical Journal 2020; 31: 61-63.
[36] Yu W, Wang ZJ, Gao DP, Zhang W, Jin W, Ma XS and Qi SH. A method for addressing right upper lobe obstruction with right-sided double-lumen endobronchial tubes during surgery: a randomized controlled trial. BMC Anesthesiol 2018; 18: 130.
[37] Eldawlatly AA. Double lumen tube: size and insertion depth. Saudi J Anaesth 2021; 15: 280-282.
[38] Shiqing L, Wenxu Q, Jin Z and Youjing D. The combination of diameters of cricoid ring and left main bronchus for selecting the “best fit” double-lumen tube. J Cardiothorac Vasc Anesth 2018; 32: 869-876.
[39] Cheong KF and Koh KF. Placement of left-sided double-lumen endobronchial tubes: comparison of clinical and fibreoptic-guided placement. Br J Anaesth 1999; 82: 920-921.

[40] Boucek CD, Landreneau R, Freeman JA, Strollo D and Bircher NG. A comparison of techniques for placement of double-lumen endobronchial tubes. J Clin Anesth 1998; 10: 557-560.
[41] Campos JH, Hallam EA, Van Natta T and Kernstine KH. Devices for lung isolation used by anesthesiologists with limited thoracic experience: comparison of double-lumen endotracheal tube, Univent torque control blocker, and Arndt wire-guided endobronchial blocker. Anesthesiology 2006; 104: 261-266, discussion 265A.
[42] Sydiuk A and Sydiuk O. New formula for selection of an appropriate left-sided double-lumen tube size in thoracic anaesthesiology. Perioperative Care and Operating Room Management 2021; 25: 100219.
[43] Yoo JY, Kang SY, Park JS, Cho YJ, Park SY, Yoon HI, Park SJ, Jeong HG and Kim T. Deep learning for anatomical interpretation of video bronchoscopy images. Sci Rep 2021; 11: 23765.
[44] Livovsky DM, Veikherman D, Golany T, Aides A, Dashinsky V, Rabani N, Ben Shimol D, Blau Y, Katzir L, Shimshoni I, Liu Y, Segol O, Goldin E, Corrado G, Lachter J, Matias Y, Rivlin E and Freedman D. Detection of elusive polyps using a large-scale artificial intelligence system (with videos). Gastrointest Endosc 2021; 94: 1099-1109, e10.